the trust placed in our Society by Miss BRUCE, to award this medal "for distinguished services to astronomy," has been kept in spirit as well as in letter, by our bestowal of it upon Geheimer Rath Dr. ARTHUR AUWERS.

In his necessary absence to-night, I hand the award to you, Mr. Secretary, to transmit to Dr. AUWERS, with the assurance of our appreciation of his great achievements, and the expression of our hope that, in the investigation of the many problems still waiting to be solved, his fellow-workers may long enjoy the advantage of his co-operation and counsel.

March 25, 1899.

SOME PHOTOGRAPHS OF THE GREAT NEBULA IN *ORION* WHICH ARE DIRECTLY COMPARABLE WITH DRAWINGS.

By JAMES E. KEELER.

In an article printed several years ago in these *Publications*,* I considered at some length the effect of a supposed non-homogeneous structure of the nebulæ on their forms as shown respectively in drawings and in photographs. The argument was briefly this: The nebula is seen by one set of rays, and photographed by a different set, so that the two different impressions cannot be expected to agree, unless these sets of rays are emitted in the same proportions by all parts of the nebula. The same considerations apply to any landscape; and it is only because the objects in a landscape have sharply defined outlines that the differences between the photograph and the view seen by the eye do not strike us more forcibly.

I do not by any means assert that the cause here mentioned is chiefly responsible for the differences between drawings and photographs of nebulæ. These differences are no doubt mainly due to the nature of the object, and the extreme difficulty of drawing faint and diffuse forms. It is sufficiently obvious, moreover, to any one who looks over such a collection of drawings as Professor HOLDEN has brought together in his "Monograph on the Central Parts of the Nebula of *Orion*," that many of the

*Vol. VII, p. 279, (1895).

observers who tried to draw this object lacked the necessary skill with the pencil. Others scribbled a rough diagram, accentuating some feature that caught their attention. As a matter of fact, drawings differ among themselves quite as much as they differ from photographs.

However, if it can be shown that the spectrum of a nebula is not the same in all its parts, the cause which I have pointed out must be operative, and only the extent of its influence can be questioned. If the differences in the composition of the light, as revealed by the spectroscope, are considerable, some striking differences between drawings and photographs may be satisfactorily accounted for.

In the case of the *Orion* nebula, differences in the spectrum were suspected many years ago by Dr. HUGGINS, and later by Dr. HENRY DRAPER. Large differences were actually found and their amounts estimated in 1893 by Professor CAMPBELL. Some doubts which were expressed as to the reality of the observed appearances have been, I think, completely removed,* and it may be regarded as certain that the *Orion* nebula has by no means the fundamental sameness of constitution which has generally been ascribed to it; but that great differences exist in the relative strength of the lines in its spectrum.

The monochromatic images of the nebula produced by an object-glass prism have been photographed by Professor WM. H. PICKERING,† who showed that some slight differences in the spectrum of the Huyghenian region could be detected in this way. But this theoretically very beautiful method is practically far from satisfactory. The separate images thus obtained are feeble, so that only the brightest part of the nebula can be photographed; the images overlap, and are therefore confused; the many stars in the nebula are drawn out into spectra, and are no longer available as reference points; and the strong continuous spectra of the brighter stars overpower and practically obliterate the images of the nebula on which they are superposed.

In the article to which I have already referred, I suggested the use of a color-screen and orthochromatic plate for accomplishing the same purpose without any spectroscopic appliances; and I have recently been able to carry out the experiments there proposed, with the aid of the Crossley reflector — an instrument

A. N., 3541.

† *Annals* H. C. O., Vol. XXXII, p. 74.

which possesses in the highest degree all the qualities required. The focal length of this telescope being nearly eighteen feet, the images are large; the ratio of focal length to aperture being about 6 : 1, the images are bright; the blue and violet rays of the spectrum are reflected with little loss; and there is no chromatic aberration such as affects the image formed by a refractor.

Two color-screens, of a yellowish-green color, were supplied by Mr. CARBUTT, the well-known dry-plate maker. The plates used were the Cramer "Isochromatic Instantaneous."

In order to understand just what is effected by the color-screen used in this way, it is necessary to consider the nature of the spectrum of the nebula, the selective absorption of the screen, and the sensitiveness of the orthochromatic plate to light of different wave-lengths.

The Spectrum of the Nebula.— If the spectrum of the brightest part of the nebula (the Huyghenian region) is examined with a spectroscope, three bright lines are at once seen. Two, about equally bright, are the Hβ line of hydrogen and the line λ 4959. The lowest line, which is several times brighter than either of these, is the "chief" nebular line, λ 5007. The Hγ hydrogen line is also visible, but it is not at all bright, and a few other lines, due to helium and unknown substances, are visible under very favorable conditions. They contribute practically nothing to the brightness of the visual image seen in ordinary observation, which is almost entirely due to the lines first mentioned.

These three lines also appear on a photograph of the spectrum, taken on an ordinary plate; but their relative intensities are now quite different. The chief line is about as bright as Hβ, and λ 4959 is considerably weaker than either. Farther up in the spectrum are other and much stronger lines. Chief among these are Hγ and other lines of the hydrogen series, and a line at λ 3727, in the ultra-violet. There is also a number of weaker lines. The three lines which are seen in visual observation contribute little to the photographic image of the nebula.

If the spectrum is photographed on an orthochromatic instead of an ordinary plate, the appearance is nearly the same, but there is an important change in the relative intensities of the three lowest lines, which now nearly agree with the visual intensities. All three lines are, moreover, much stronger than before, as compared with lines in the upper spectrum.

Curve of Sensitiveness of an Orthochromatic Plate.— The sensitiveness of an ordinary dry plate is widely different for light of different colors. It may be conveniently represented by the height of a curve drawn above a map of the spectrum. Experiment shows that this curve rises gradually from the extreme ultra-violet to a maximum near the line Hγ, from which it falls more abruptly toward Hβ. Without forced exposure (seldom possible in astronomical photography), it does not extend much beyond this line.

Isochromatic plates (notwithstanding their name) also vary greatly with respect to their sensitiveness to light of different colors. The curve of sensitiveness is, in its upper part, quite like that of an ordinary plate, having a maximum at Hγ, but instead of ending it merely sinks to a minimum below Hβ, and then rises again to another, though lower, maximum in the yellow.

These properties of photographic plates explain the differences in the relative intensities of the three lowest nebular lines, which have already been described. The lowest line, which is brightest to the eye, does not affect an ordinary plate so strongly as the weaker line Hβ. On an orthochromatic plate, owing to the rise of the curve of sensitiveness toward the yellow, the brightest line is also photographically the strongest.

Selective Absorption of the Color-Screen.— The color-screens used in photography, like colored glasses in general, act by the absorption or suppression of certain kinds of light. The rays to which they owe their color are transmitted.

A color-screen, to be effective for the purpose now under consideration, must transmit the light of the three lowest nebular lines, and absorb all light of shorter wave-length. Since the nebular lines are in the green or bluish-green part of the spectrum, the color of the screen must be green.

It was found by visual and photographic observations of the solar spectrum, and also of the spectrum of hydrogen, that both the screens supplied by Mr. CARBUTT completely suppressed the ultra-violet, violet, and blue rays, the absorption extending down as far as Hβ. One of the screens, which has a strongly yellowish-green color, absorbs even the light in the region of the nebular lines to a considerable extent, and although the effect of this absorption was to render the photographed nebular lines more

nearly with their visual relative intensities, the screen had to be rejected as the loss of light proved to be important. The other screen, which has a light-green color, was therefore chosen for the observations. Both screens, of course, strongly absorb the red, where their action is, however, immaterial in connection with the present investigation.

It will be seen from the foregoing considerations that when the spectrum of the nebula of *Orion* is photographed through the color-screen, on an orthochromatic plate, it is reduced to the three lines seen in visual observation, and that the visual relative intensities of these lines are approximately preserved. Hence a photograph of the nebula itself, taken in the same way, is directly comparable with the image of the nebula which is seen in the telescope in ordinary observation.

The Crossley reflector has a double-slide guiding apparatus of the form devised by Dr. COMMON. Small errors, due to irregular driving, changes of flexure, refraction, etc., are corrected by screws which move the plate-holder, the observer guiding by means of an eyepiece, with illuminated cross-wires, which is set on a star as close as possible to the edge of the ($3\frac{1}{4} \times 4\frac{1}{4}$) plate.

The color-screen was mounted immediately in front of the photographic plate, in a light frame which could easily be removed. On account of the large angular aperture of the reflector, the change of focus produced by the screen was quite perceptible, and had to be allowed for when the screen was inserted or removed.

With this apparatus a number of photographs of the *Orion* nebula were taken during the past winter, together with many photographs on ordinary plates, without the color-screen, for purposes of comparison. But it is not permissible to compare photographs taken by these two different methods without taking into account certain peculiarities of photographic action which have a great influence on the character of a negative. Every photographer knows that the densities of different parts of a negative are not by any means proportional to the different brightnesses of the objects which they represent. With lights of given intensity the relative density of the images, or amount of contrast, depends upon the length of exposure, quickness of the plate, manner of development, and other factors, and it can be made to vary within very wide limits. It is quite possible, for example, to reverse the order of brightness, so that the brighter

object shall give the weaker image. These facts depend on principles which are constantly taken advantage of in ordinary pictorial photography.

We may, however, safely assume, if we leave out of consideration certain cases not likely to occur in such investigations as these, that if all the conditions, including the quality of the light, have been the same, equally dense parts of the negative have been produced by equally bright parts of the object. Comparisons of some value can be made even on a basis no wider than this. But as I wished to draw conclusions from differences as well as from equality of density, efforts were made to obtain photographs, by the different methods, which should be directly comparable in this respect. What I aimed at, therefore, was to produce two photographs of the nebula on the same night, one taken on an ordinary plate and in the ordinary manner, the other taken on an orthochromatic plate through the color-screen, the exposures in the two cases being so timed that the two negatives, when placed in a tray and developed together, should develop in the same manner, and should appear equally dense when fixed. The conditions, as stated, apply to the Huyghenian region. On some occasions they were pretty nearly fulfilled.

For example, on February 9, 1899, an orthochromatic plate, protected by the color-screen, was exposed in the telescope for two hours and twenty minutes. The screen was then removed, the focus readjusted, and exposures of four, five, and six minutes, respectively, were given to three ordinary plates. The four plates were placed in a tray and developed together, when it was found that the four-minute plate and the orthochromatic plate developed with about equal rapidity, the Huyghenian region "coming up" in the same manner on both plates.

I had hoped that a moderate exposure through the color-screen would be sufficient to show a large amount of nebulosity, giving such a picture of the nebula as the eye would see if its sensitiveness could be greatly increased. But the first experiments showed that the photographic activity of the rays transmitted by the screen was so small that such a result could not possibly be obtained. This is evident from the example already given, the exposure in one case being thirty-five times that in the other.

However, the failure of the orthochromatic plate to show a great amount of nebulosity is not entirely caused by the insensitive-

ness of the plate to the nebular rays of low refrangibility. Comparing two plates taken in the manner described above, on which the Huyghenian region has the same density, I find that a much greater amount of nebulosity is shown on the ordinary dry plate. Conversely, if the two photographs show approximately the same amount of diffuse nebulosity, the Huyghenian region is very much stronger on the orthochromatic plate. This is the chief result of the investigation. It shows that, compared with the Huyghenian region, the nebular lines of the visual spectrum are faint, and the hydrogen lines strong, in the remote portions and outlying streamers of the nebula. Thus the spectroscopic observations made at Mt. Hamilton are confirmed, and the conclusions based on them extended to parts of the nebula which are beyond the reach of visual methods.

A valuable check on the comparisons is afforded by the numerous stars which are scattered through the nebula. These stars are presumably, like nearly all the stars in the same constellation, and particularly stars which are involved in the nebula, of the first spectral type, and rich in ultra-violet light. Their actinic power is therefore reduced by the screen in at least as great a ratio as that of the nebula. Hence if on plates with equally dense images of the Huyghenian region, taken by the two different methods, the stars appear in equal number and with equal strength (which is approximately the case), while the diffuse nebulosity is extremely weak on the one taken with the color-screen, the explanation can only be that which has already been given. Such is in fact the nature of the difference between plates compared in this manner.

The orthochromatic photographs, in giving great relative strength to the Huyghenian region, are evidently in accordance with drawings. Some more special results of the comparison of the two different kinds of photographs are given below.

Extending from the southeast corner of the Huyghenian region toward the south, is a long scimetar-like streamer which is visible in quite a small telescope. It was in fact discovered by MESSIER, as long ago as 1771. Close to it, on the west, and running parallel to it, is a shorter streamer, which is not easily visible, even in a large telescope. It is not shown in the drawings of HERSCHEL, Lord ROSSE, BOND, TROUVELOT, or in any of the drawings I have examined except one — the drawing made by LASSELL in 1862.

These two branches of the nebula are well shown in the photograph which forms the frontispiece of No. 66 of these *Publications*, and it will be observed that they have nearly the same intensity. Even with much shorter exposures, on ordinary plates, it is difficult to obtain an impression of the stronger branch without some indication of the existence of the weaker.

This discrepancy between celebrated drawings and photographs taken by the usual methods is explained at once by these investigations. The orthochromatic photographs and the drawings agree. On the plates taken with the color-screen the Messerian branch is strong and distinct, the companion only faintly visible. The inference is that in the spectrum of the former the lowest nebular lines are relatively strong, while in that of the latter the lines of hydrogen predominate.

The nebulosity surrounding the star Bond 734, north of the main nebula, is greatly weakened by the color-screen, a fact which shows that the less refrangible nebular lines are weak in this region, and confirms the spectroscopic observations made at Mt. Hamilton. The image photographed through the color-screen is no doubt almost entirely due to the light of the Hβ line.

West of the nebula, ordinary photographs reveal some beautiful curves of nebulosity, with bright scalloped edges which are nearly as bright as the Messerian branch (see the frontispiece, No. 66). They are easily photographed with an exposure of two minutes. They are not visible, however, in the telescope, and of course are not shown on any drawing of the nebula. These bright curves of nebulosity are faintly shown on only one of my photographs taken with the color-screens. The explanation is the same as that which has been given for the other cases considered.

Some other differences are brought out by comparisons like these, but the above are the most interesting cases.

The photographs taken through the color-screen are not suitable for reproduction, on account of the great differences of density which they exhibit. I have therefore merely described the results obtained by comparing them with ordinary photographs, and have given the conclusions which I think one is justified in drawing from the comparison. In the photographic work at the telescope I had the efficient assistance of Messrs. E. F. CODDINGTON and H. K. PALMER, Fellows at the Lick Observatory.

The foregoing article contains, in somewhat more popular form, the substance of a paper contributed to the *Astrophysical Journal.*